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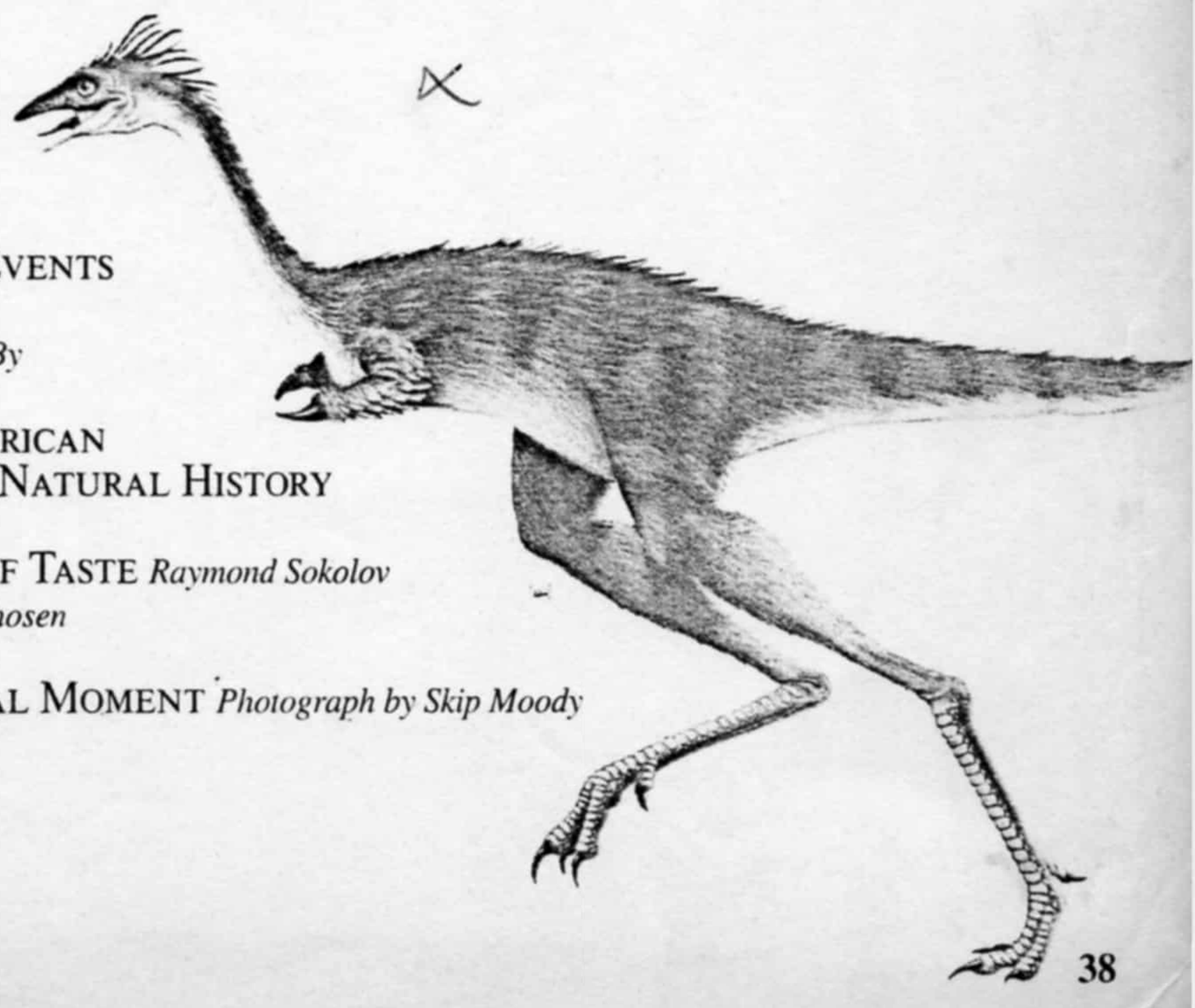

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30 NOV 1993

New Limb on the Avian Family

Where does a wingless, clawed bird from Mongolia fit in?

by Mark Norell, Luis Chiappe, and James Clark

For the last four summers, field parties from the American Museum of Natural History have traveled to the badlands of southern Mongolia looking for fossils from the age of dinosaurs. These expeditions continue a tradition of Museum exploration in Mongolia that started in the 1920s. Led by Museum paleontologists Roy Chapman Andrews and Walter Granger, the Central Asiatic Expeditions discovered some of the world's greatest dinosaur localities, including the Flaming Cliffs (so named because of their brilliant red color), where the first dinosaur eggs were found.

As members of the American Museum's recent joint expeditions with the Mongolian Academy of Sciences, we have revisited some of the classic localities, prospected some others discovered by Soviet, Mongolian, and Polish teams, and found a few new sites of our own. All the members of the current expedition have their own reasons for wanting to explore the rich fossil beds of the Gobi Desert. One of our main motivations was the possibility of finding dinosaur fossils that would shed light on the origin of birds.

When the first 145-million-year-old fossils of *Archaeopteryx* were unearthed more than a hundred years ago in Bavarian stone quarries, they were immediately hailed as the link between reptiles and birds. Although *Archaeopteryx* had teeth and a long reptilelike tail, it also had wings and feathers and was probably able to fly. But new discoveries and theories have recently rekindled the debate over just how birds evolved. Birds are now considered to be a subgroup of dinosaurs, descended from fast-moving, bipedal carnivores that *Archaeopteryx* greatly resembled. But we know few specifics about the transition from typical dinosaurs to birds and about early bird diversification. This is largely due to the lack of well-preserved fossils. Skeletal lightness is the key to flight, but thin, hollow bones also break quickly after a bird dies and are preserved as fossils only under extraordinary circumstances.

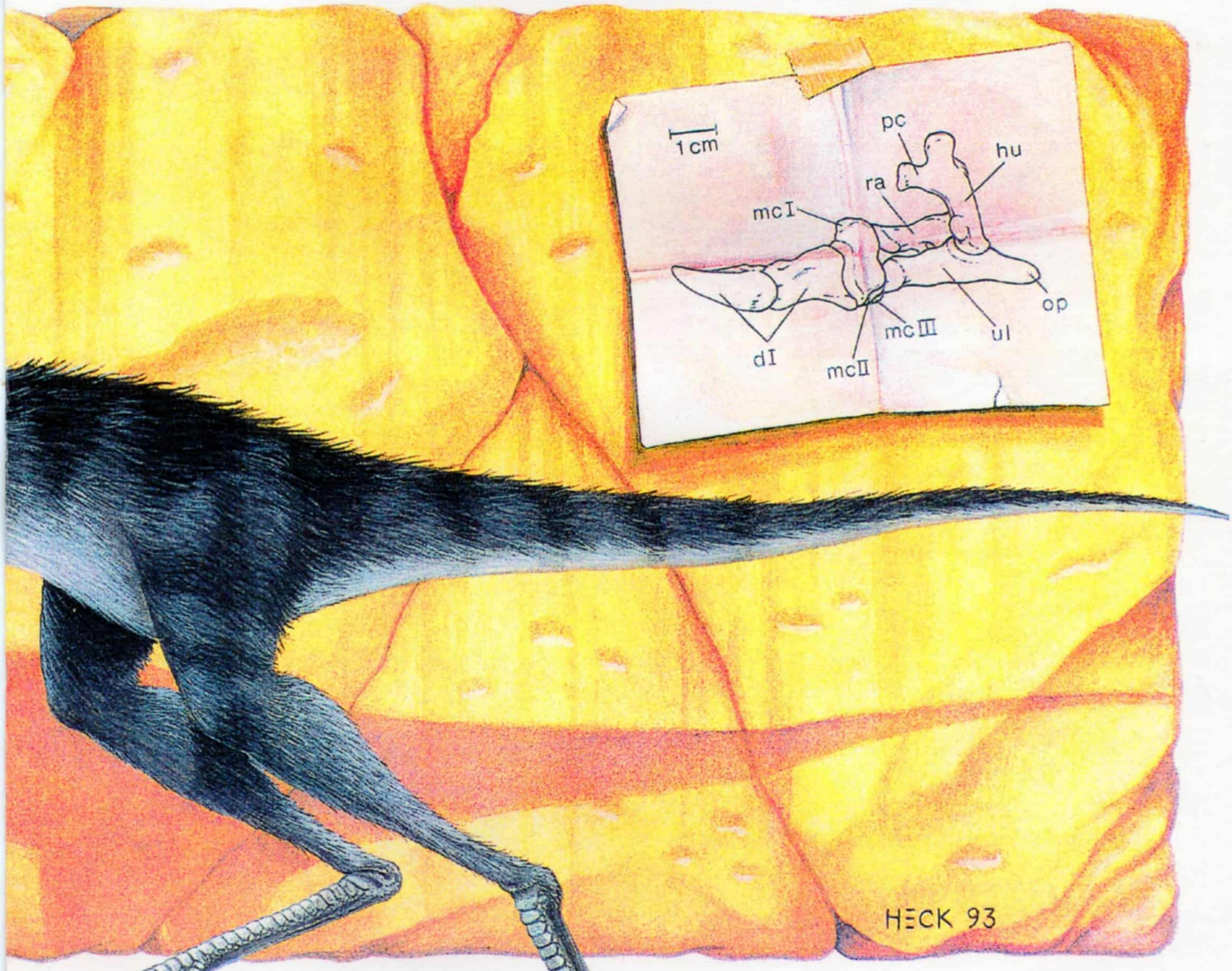
The few known specimens have been preserved through chance—some birds happened to perish in an environment conducive to preservation. *Archaeopteryx* and two recently discovered sparrow-sized, early Cretaceous fossil birds, *Iberomesornis* from Spain and *Sinornis* from China, were found in fine-grained, thin-bedded deposits that were once ancient lagoons or lakes. Fossils created in these conditions can be spectacular. Many even reveal delicate feather impressions. Yet other important physical features cannot be fully examined because the bones in these fossils have been smashed flat—preserved in essentially two dimensions. Well-preserved, three-dimensional fossil material is vital to a better understanding of the entire question of bird origins.

Mongolia, a prime site for such material, has yielded both primitive birds and the small theropod dinosaurs thought to be close relatives of birds. One striking example is a rock-encased *Velociraptor,* a small, swift, carnivorous theropod dinosaur, entwined in a death struggle with a *Protoceratops,* a plant eater abundant in Cretaceous times. Among the world's paleontologic treasures, these fossils were discovered in the 1960s by Perle Altangerel (a Mongolian participant in our recent joint expeditions), and by Polish colleagues. During our first three field seasons in the Gobi, we, too, have had the good fortune to unearth several new dinosaur specimens; one of these has given us new insights into the origin of birds.

At the start of the 1991 expedition, we were in Ulan Bator, Mongolia's capital city, preparing for the two-month excursion to the Gobi, when Perle Altangerel showed us an unusual specimen, collected in 1987 in south-central Mongolia. At first, we could hardly believe that the bones were the remains of a single animal—they looked as if they belonged to two different crea-

Tree

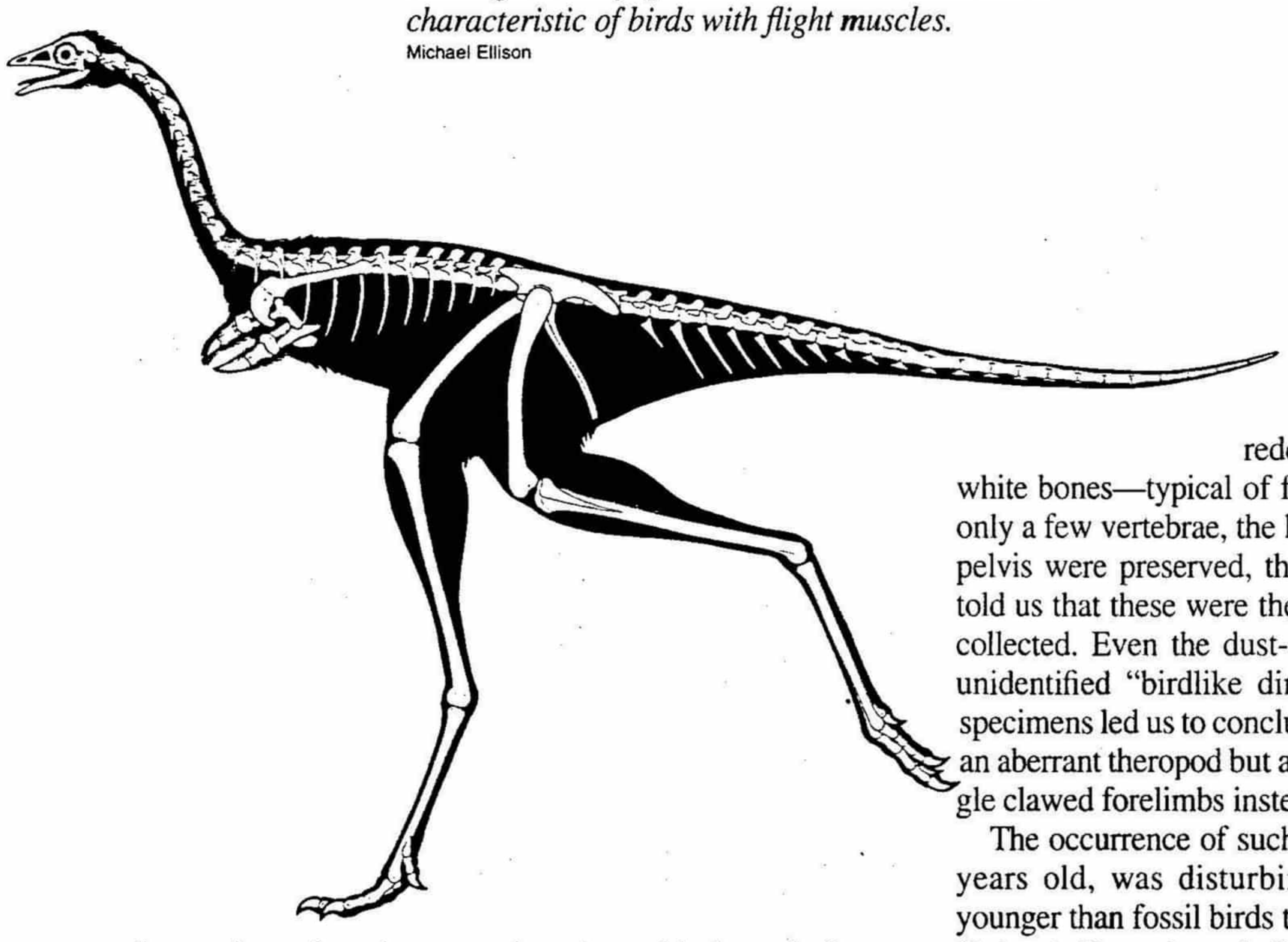
Mononykus, *which lived some 70 million years ago in what is now the Gobi Desert, may have used its stout front claws for digging.*
Painting by Ed Heck



tures. But Perle assured us that they had been found in a single place with all of the bones articulated, or still arranged as in life. The hind limbs were long and birdlike, about the size of a turkey's, while the front limbs were tiny. Typically, in theropod dinosaurs, if the front limbs are small, they are also weak. The front limbs of this animal were short and small, but all of the bones had the sort of large protuberances and processes that one sees in heavily muscled burrowing animals. At the end of the arm, instead of the usual multiple "fingers" seen in most four-legged animals, was a single, powerful finger terminating in a stout, hooked claw. For this reason, Perle had named the creature *Mononykus olecranus*, the genus name meaning "one-claw."

In our minds, we cataloged this fossil as an interesting anomaly until Perle brought it to New York during a visit in 1992. On seeing it again, we compared it with a specimen that American Museum paleontologist Malcolm McKenna had found in July 1992 about forty-five miles northwest of the Flaming Cliffs at Tugrugeen Shireh (the site that had yielded the dinosaurs locked in combat). Among the loose bits were bones that were smaller versions of the ones Perle had found. Associated with these bits, Malcolm had also found a small skeleton, which he excavated and encased in a plaster jacket. We began to extri-

Toothed and long-tailed like many other small theropod dinosaurs, Mononykus *also has defining avian features. Although it was flightless, its keeled breatsbone is characteristic of birds with flight muscles.*
Michael Ellison

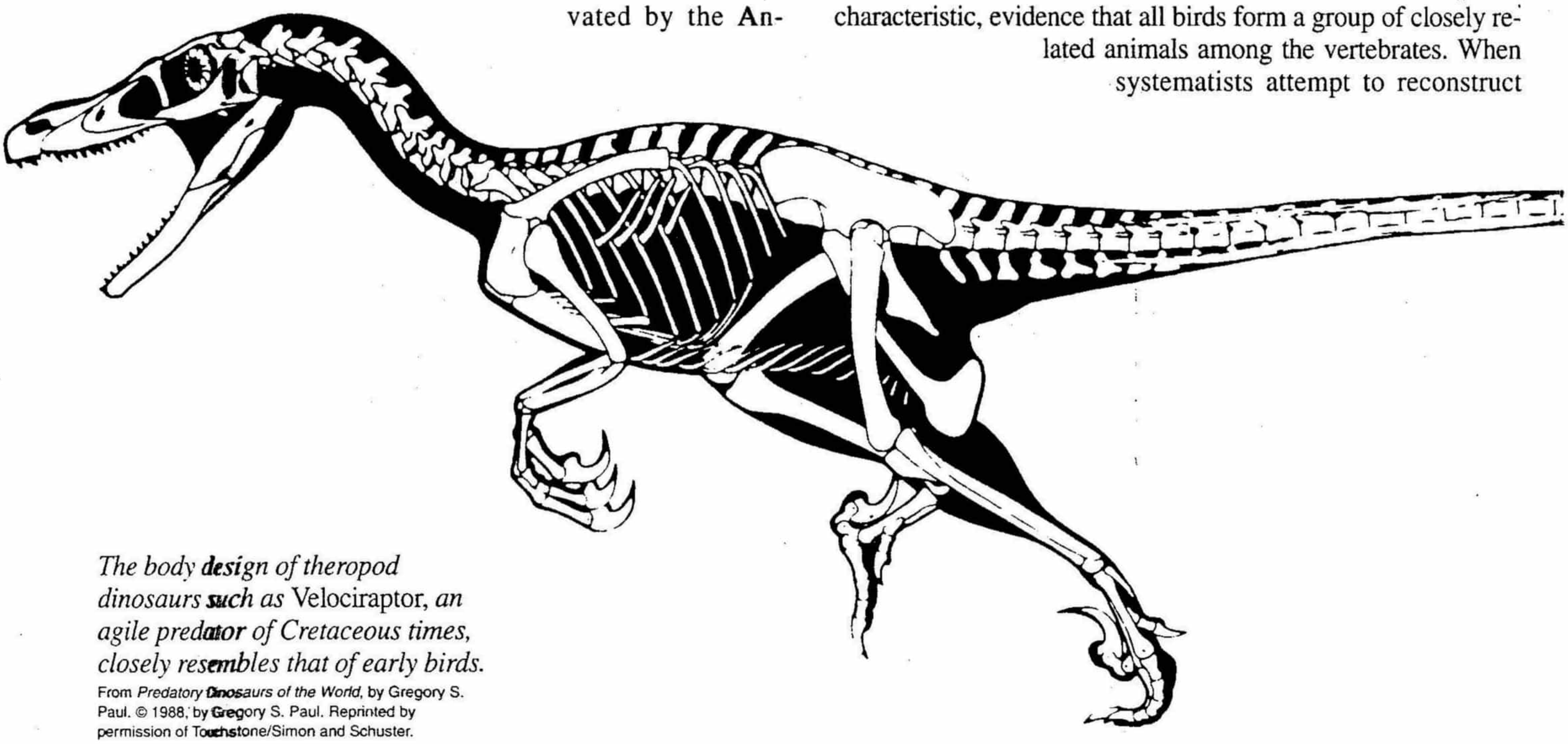


cate the specimen from its protective plaster block, and after a few days, the legs and tail of a small animal emerged. The hind limbs were structurally identical with those collected by Perle two years earlier at Bugin Tsav, but they were about one-third smaller, perhaps representing a juvenile. More important, this specimen, preserved in three dimensions, had a nearly complete pelvis, a long, articulated tail, and a complete foot.

During the spring of 1993, more specimens of this group turned up. One fragment had been collected during our 1992 expedition. Another had long been sitting in the Museum's own collection. Excavated by the Andrews expedition, it was brought to our attention by Bryn Mader, of the Museum's Department of Vertebrate Paleontology. It was a small, reddish lump with a few exposed, eroded white bones—typical of fossils from the Flaming Cliffs. While only a few vertebrae, the hind limbs, and parts of the distinctive pelvis were preserved, these sparse, heavily abraded elements told us that these were the remains of the first *Mononykus* ever collected. Even the dust-covered label proclaimed it to be an unidentified "birdlike dinosaur." Taken together, these three specimens led us to conclude that *Mononykus olecranus* was not an aberrant theropod but a primitive bird—a bird with short, single clawed forelimbs instead of a more typical wings.

The occurrence of such a primitive bird, at about 70 million years old, was disturbing because *Mononykus* was much younger than fossil birds that appear more advanced. Feathered, flighted *Sinornis* and *Iberomesornis,* for example, predate *Mononykus* by about 40 million years. In addition, both the more advanced, but flightless, diving bird *Hesperornis* and fully flighted ancestors of modern birds were contemporaries of *Mononykus.*

Our reasons for considering *Mononykus* a bird are based on the presence of several evolutionary novelties shared by *Mononykus* and birds. These novelties—or derived characteristics—are the criteria that systematists use to group organisms and to reconstruct their family trees. For example, all feathered vertebrates (birds) have backbones, but not all organisms that have backbones have feathers. So feathers constitute a derived characteristic, evidence that all birds form a group of closely related animals among the vertebrates. When systematists attempt to reconstruct



The body design of theropod dinosaurs such as Velociraptor, *an agile predator of Cretaceous times, closely resembles that of early birds.*
From *Predatory Dinosaurs of the World,* by Gregory S. Paul. © 1988, by Gregory S. Paul. Reprinted by permission of Touchstone/Simon and Schuster.

From "Early Evolution of Avian Flight and Perching: New Evidence from the Lower Cretaceous of China," by P.C. Sereno and R. Chenggang, *Science* (February 1992) 255:845–48, © AAAS

Feathered and probably able to fly, the crow-sized Archaeopteryx, *below, reflects a mixture of reptilian and avian traits. Both* Archeopteryx *and the sparrow-sized flying bird* Sinornis, *left, are much older than* Mononykus.

From *Predatory Dinosaurs of the World*, by Gregory S. Paul. © 1988, by Gregory S. Paul. Reprinted by permission of Touchstone/Simon and Schuster.

family trees or place newly discovered animals like *Mononykus* into context, they look for derived characters, such as feathers, that are evidence for subgroups that share a common ancestor.

Despite its lack of wings and the many primitive features reminiscent of its dinosaur ancestors (including teeth, a long tail, and foot bones that are separate from one another), the bizarre *Mononykus* had several birdlike characteristics that are not found in *Archaeopteryx* specimens. These include a breastbone with a strong median keel, a fibula that is reduced to a small spike (like the thin bone of a drumstick), and fused wrist bones. These derived traits, shared with modern birds, place it firmly in the subgroup with other avians.

What is the place of *Mononykus* in the evolutionary history of birds? Currently, the oldest-known bona fide birds are the 145-million-year-old *Archaeopteryx* and the 100-million-year-old *Iberomesornis* and *Sinornis*. Certainly, mononykosaurs (*Mononykus* and its relatives) have a lengthy history that is unrecorded in the fossil record, and the discovery of *Mononykus* still leaves great gaps in our knowledge of the evolutionary events that took place between *Archaeopteryx* and the origin of modern birds. The specialized forelimbs and late geological age of *Mononykus* tell us that it cannot be a direct ancestor of modern birds. We will continue to search both in the field and in our Museum collections for other kinds of mononykosaurs and to fine-tune the position of these animals in the family tree of birds and theropods.

Mononykosaurs are animals of Dr. Seussian dimensions. Much of the skeleton looks pretty average for that of a small theropod. Only with the strange front limbs do we get into trouble. What could they possibly have been used for? Forelimb modification is a recurring theme in theropods—both dinosaurian and avian. (Among these are the diminutive arms of *Tyrannosaurus rex,* the elongated arms of some Mongolian theropods, and the flippers of penguins.) But the short, muscular, clawed arms of *Mononykus* are among the most bizarre we have ever encountered.

Living animals with strong, clawed front limbs are diggers. The actual muscle power can be determined from the size of the series of crests on the arm bones, which, in life, anchored big muscles. This musculature was further empowered by the architecture of the arm bones. The olecranon process of *Mononykus,* which is equivalent to our elbow, is as long as the forearm. Muscles attaching to the olecranon process give tremendous leverage to the forearm, in much the same way that a long-handled shovel works better than a short-handled one. The bone surfaces indicate that movement was predominantly in a single plane, with the massive fingers moving inward toward the middle of the body. Our best guess is that *Mononykus* was an animal that fed much as aardvarks or anteaters do today, using its brawny front limbs to tear apart plants (or perhaps insect nests) while foraging on the ground.

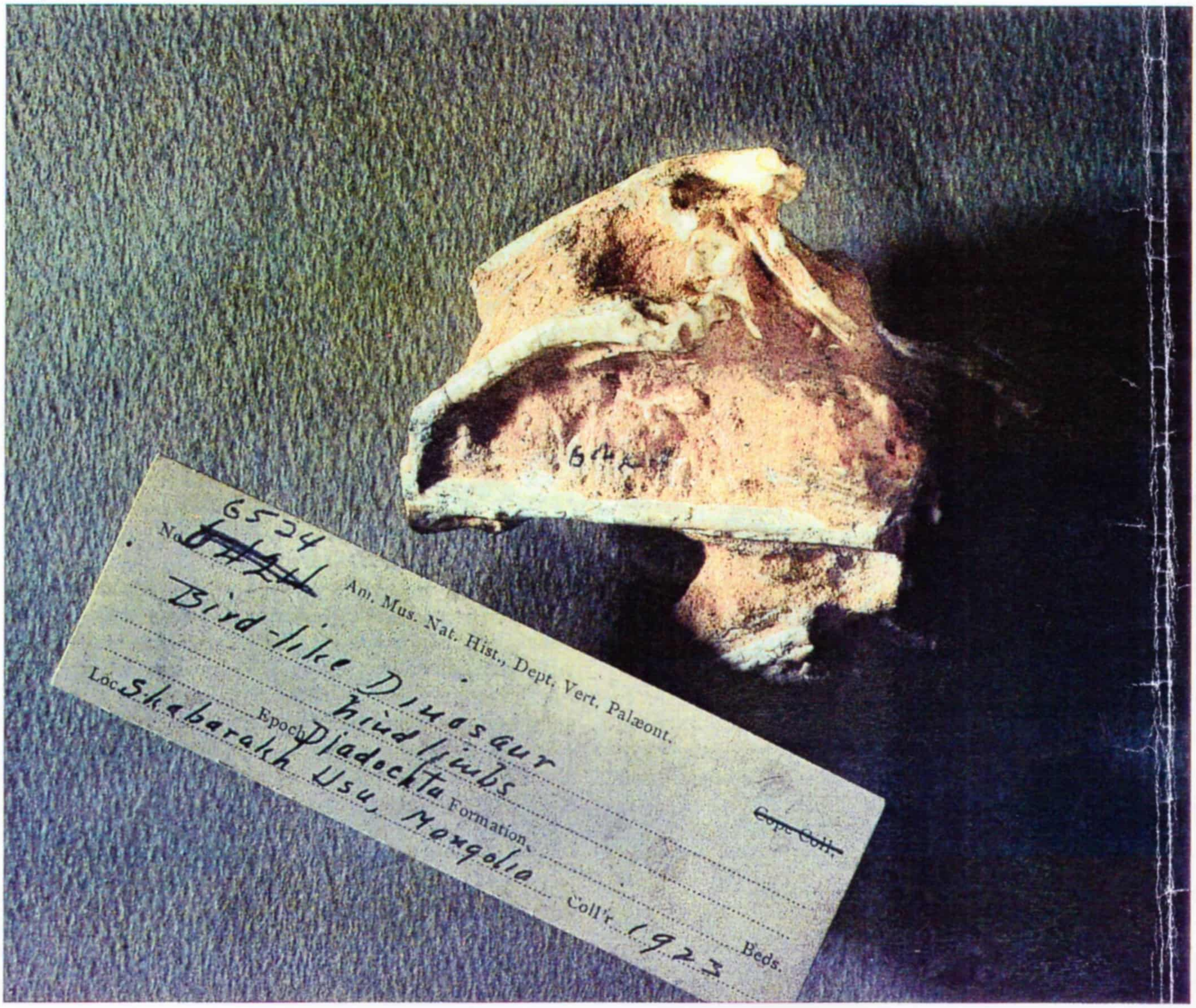
Present-day birds have highly modified forelimbs, usually associated with the evolution of powered flight. These specializations include a reduction in the number of digits (birds have just one primary digit homologous to a single human finger), the fusion of all the wrist bones into a single inflexible element, and a reorientation of the top of the upper arm bone. These forelimb specializations link *Mononykus* with modern birds.

But this complicates the story of the origin of flight. Most authorities feel that *Archaeopteryx* could fly, although just how adept a flier it was is a matter of debate. More advanced birds like *Sinornis* and *Ibermesornis* definitely flew. *Mononykus,* however, was undoubtedly a ground dweller. Its privileged position in the avian family tree—nearer to modern birds than to *Archaeopteryx*—suggests two very different, but plausible, scenarios for the evolution of flight.

In one scenario, the common ancestor of *Archaeopteryx* and modern birds had some degree of powered flight, but the ability to fly was later lost in the lineage leading to mononykosaurs, as

Labeled "birdlike dinosaur," Mononykus *fossil fragments, below, were excavated during the 1923 Gobi expedition. This American Museum specimen and more complete fossils fresh from the field revealed that* Mononykus *was a flightless bird. The remains of* Archaeopteryx, *right, are among the best and earliest examples of fine preservation of fragile bones.*

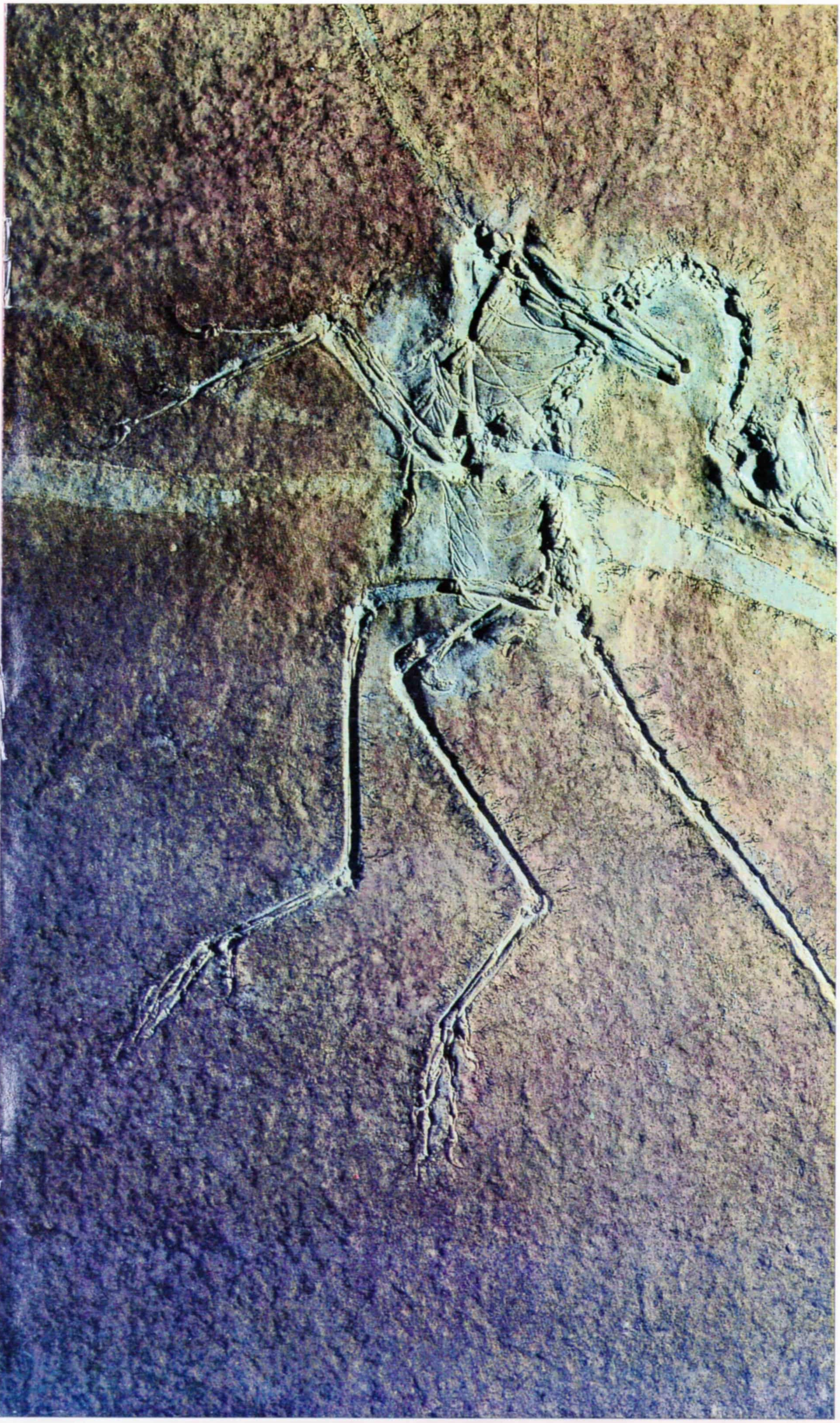
Photographs AMNH



it has been in birds such as kiwis, ostriches, and some rails. In the second scenario, the original bird ancestor was flightless, and the ability to fly arose twice—once in the lineage leading to *Archaeopteryx* and again in the lineage leading to modern birds, some time after mononykosaurs split off from the latter line. This second possibility has important ramifications—if it is true, then *Archaeopteryx* may not be relevant to the origin of what we think of as modern bird flight. Instead, our inquiries should focus on the ground-dwelling *Mononykus* as the closest relative of the first modern flying birds.

Could flight have arisen twice in the history of birds? This scenario is not as convoluted as it may seem. *Mononykus* does exhibit a keeled sternum for attachment of developed muscles and the fusion of the wrist bones. Conceivably, these elements arose in *Mononykus* ancestors for some other function, such as digging, and were subsequently co-opted for flight.

As paleontologists and systematists, one of our goals is to understand how organisms interrelate. As more creatures like *Mononykus* are discovered, the family tree is readjusted to make room for the newcomers and often to reflect new thinking about relationships within groups. In our wildest dreams, we would never have imagined that our best-preserved representative of the early evolution of birds would be as unusual as *Mononykus*. The discovery of such specimens shows that the boundary between modern birds and their typically dinosaurian ancestors is a diffuse one and that the path of early bird evolution is a circuitous one. The true importance of *Mononykus* may be the unexpected twist it adds to the story of early bird evolution. □



AUTHORS

For the past four summers, Mark Norell (page 38), an associate curator of vertebrate paleontology at the American Museum of Natural History, has traveled to the Gobi Desert of Mongolia in hopes of finding fossils that shed light on the evolution of reptiles, dinosaurs, and birds. Continuing a tradition of Central Asian exploration begun by the American Museum of Natural History in the 1920s, Norell (above) and other members of the recent expeditions have excavated fossils that will help clarify the relationships among and within major groups of vertebrates. However, the discovery in 1992 of the wingless bird *Mononykus* by Norell, coauthor **Jim Clark**, and Mongolian expedition member Perle Altangerel raises questions concerning how modern birds evolved and how flight originated. Clark, a postdoctoral fellow at the American Museum, earned his doctorate from the University of Chicago. In the field, he focuses on finding smaller, often overlooked fossils from the age of dinosaurs. Coauthor **Luis Chiappe** received his doctorate from the National University in Buenos Aires and is currently a research fellow at the American Museum specializing in Mesozoic birds. More information on carnivorous dinosaurs and their avian relatives can be found in *Predatory Dinosaurs of the World: A Complete Illustrated Guide,* written and illustrated by Gregory S. Paul (New York: Touchstone Books/Simon and Schuster, 1988).